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March 29, 2019

BY ELECTRONIC FILING

Marlene H. Dortch, Secretary
Federal Communications Commission
445 12th Street SW
Washington, DC 20554

Re: Unlicensed Use of the 6 GHz Band, ET Docket No. 18-295

Dear Ms. Dortch,

On March 27, 2019 Chris Szymanski and Dr. Vinko Erceg of Broadcom Inc. and I met with Ira Keltz, Paul Murray, Syed Hasan, Jamison Prime, and Aspasia Paroutsas of the FCC's Office of Engineering and Technology.[1] We discussed the enclosed presentation which details Broadcom's research into the characteristics of Fixed Service receivers and, specifically, these receivers' available link margin, and the relationship between various Fixed Service use cases and available link margin.

As Broadcom and others have demonstrated,[2] any meaningful interference to 6 GHz licensees is extremely unlikely due to the complementary radiofrequency and operational characteristics of Fixed Service and unlicensed RLAN operations. This additional research demonstrates that, in the rare event that interference could exceed the highly protective -6 dB I/N threshold, that interference is exceedingly unlikely to constitute *harmful* interference due to the available link margin.

Sincerely,

Paul Caritj
Counsel for Broadcom Inc.

[1] Vinko Erceg participated telephonically.

[2] *See, e.g.*, Comments of Broadcom Inc., ET Docket No. 18-295, at 6–24, 27–34 (filed Feb. 15, 2019); Comments of Apple Inc., Broadcom Inc., Cisco Systems, Inc., Facebook, Inc., Google LLC, Hewlett Packard Enterprise, Intel Corporation, Marvell Semiconductor, Inc., Microsoft Corporation, Qualcomm Incorporated, and Ruckus Networks, an ARRIS Company, ET Docket No. 18-295, at 19–29, 40–45, Appendix B (filed Feb. 15, 2019).

Supplemental FS Margin Analysis

Christopher Szymanski
Vinko Erceg

March 27, 2019

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Overview

- RKF published a report (Jan-2018) considering 91,187 fixed links listed in ULS as of March 21, 2017 operating in the Continental US in the 6 GHz band, that concluded:
  - Interference exceeding the long term interference protection criteria of -6 dB I/N was extremely rare (even when accounting for 36 dBm EIRP with no AFC)
  - Median FS margin was over 50 dB
  - National deployment of RLANs would not impact the availability design target of fixed links (e.g., a link designed for 99.9999% would continue to operate at 99.9999% availability)

- In our comments, Broadcom provided a geometric analysis that further highlighted why interference exceeding -6 dB I/N would be extremely rare for low power indoor devices and for very low power portable devices

- In our reply comments, Broadcom provided a supplemental FS Margin Analysis of Part 101 fixed links and determined that FS links typically have link margin well over what is necessary to maintain operations – even when accounting for deep fade (e.g., margins in excess of the 25-40 dB target fade margin listed by FWCC)

- We conclude that interference is extremely rare, and in the event that an RLAN hits the "interference lottery" with regard to a specific FS receiver, that FS link is likely to have more than sufficient margin to continue to meet the operator's availability design targets, even during a deep fade

MARGIN ANALYSIS OF NEW PART 101 LINKS OVER PAST 2 YEARS

Link Margin Analysis Introduction

- Conducted a supplemental FS margin analysis of Common Carrier, Public Safety, and Microwave Industrial/Pool fixed paths licensed between March 21, 2017 and January 23, 2019
  - Considered a population of 5,414 new CF, MW, and MG paths using QAM modulations
  - Applied all of the assumptions contained in our comments (i.e., 5 dB noise figure, 2 dB feeder loss, 1 dB system loss), which led to a 4 dB reduction in FS margin across the board for all FS links studied as compared to RKF's methodology
  - Applied all other assumptions from RKF's methodology

- Separately studied links that listed only a single modulation and links that listed multiple modulations
  - Approximately 40% of links (2110/5414) listed only a single modulation* and 60% of the links (3304/5414) listed multiple modulations

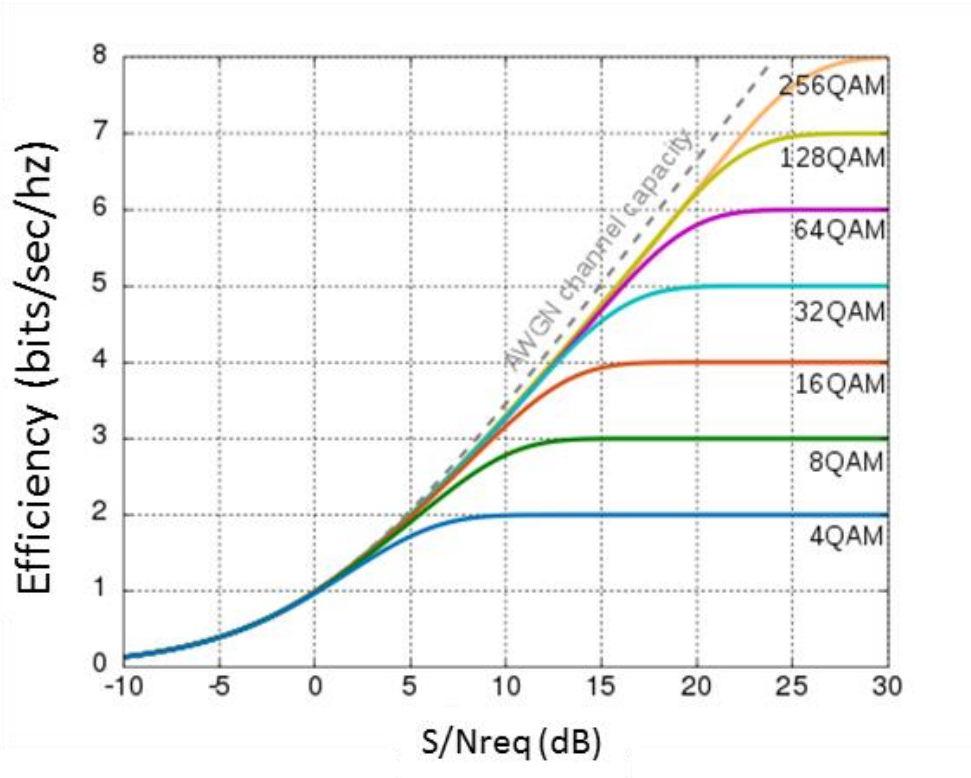
- For links listing multiple modulations, we assumed adaptive modulation, and we determined the FS margin beyond what was required for:
  - The highest modulation rates listed
  - 64 QAM (or the closest modulation to 64 QAM)
  - The lowest modulation listed (typically QPSK)

*There were a number of links that listed only a single higher order modulation (e.g., 256 QAM), so it may be the case that these links also support variable modulation, and may be capable of adaptive modulation

Link Margin Determination

- We calculated **FS link margin** as follows:
  - *Link Margin = EIRP - PL + Gr - F - S - NF - S/Nreq (dB) - 10 x log (K x 290 x B)*
- S/Nreq derived from the modulation and Baseband Digital Rate (e.g., data rate) listed in the ULS:
  - Calculated spectral efficiency (bits/sec/Hz) by dividing the data rate by bandwidth**
  - Applied theoretical capacity curves to the right for the QAM modulation listed to determine S/Nreq***

- *EIRP* = Effective isotropic radiated power (dBW) → Note: Used highest listed Tx EIRP when links listed multiple powers
- *PL* = Free space path loss (dB)
- *Gr* = FS receive antenna gain (dBi)
- *F (Feeder Loss)* = 2*
- *S (System Loss)* = 1*
- *NF (Noise Figure)* = 5*
- *S/Nreq* = Required signal-to-noise ratio (dB)
- *K* = Boltzmann's constant = 1.38064852 × 10^{-23} m^2 kg s^{-2} K^{-1}
- *B* = Signal bandwidth (Hz)



* Assumptions varying from RKF's original assumptions

** Corrected the data rate information for unit mismatch (e.g., bps, kbps, mbps) or errors in the number of zeros (i.e., too many or not enough)

***Modern equipment typically approaches theoretical efficiency. In cases where radio is less efficient, analysis would only be changed by a few dB.

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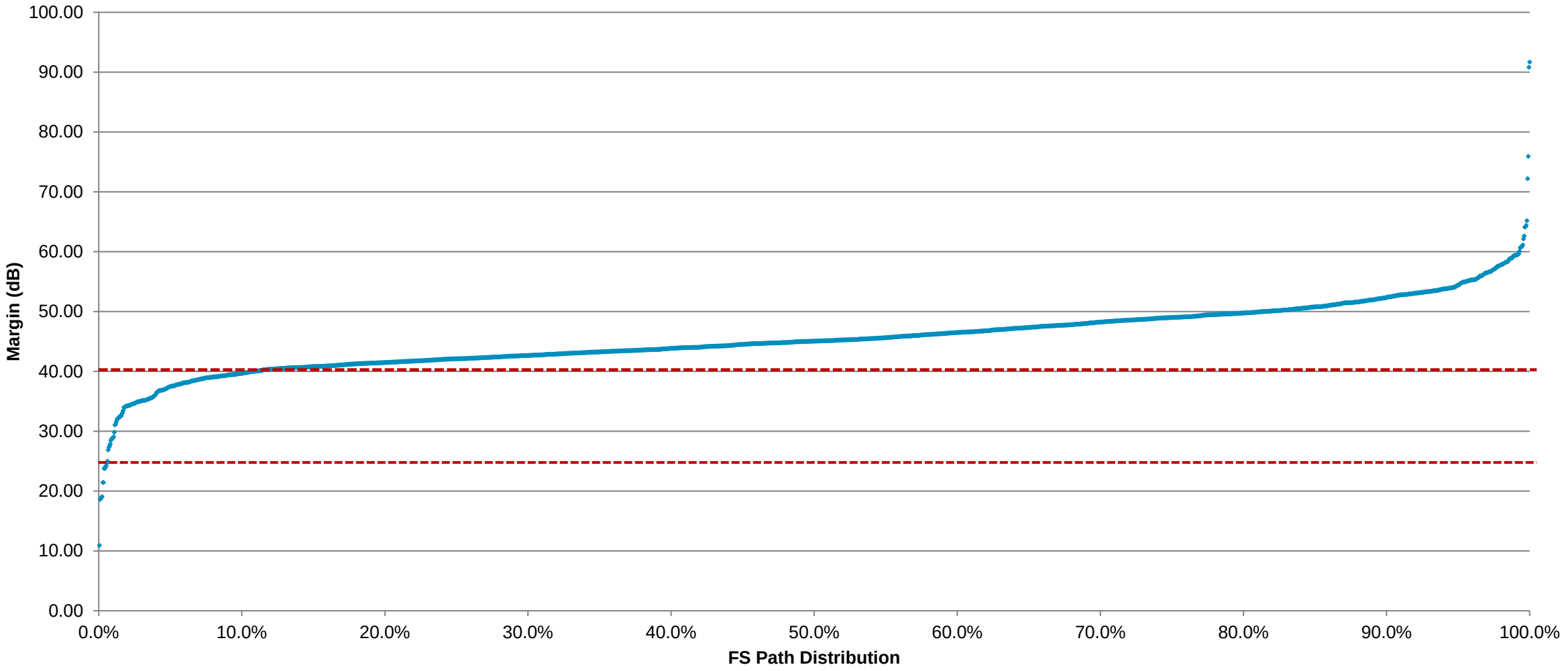
ANALYSIS OF LINKS LISTING ONLY SINGLE MODULATION IN ULS

Margin for 2110 FS Paths with Single Modulation Listed

Virtually all links have over 25 dB in margin, and 90% have over 40 dB for listed modulation



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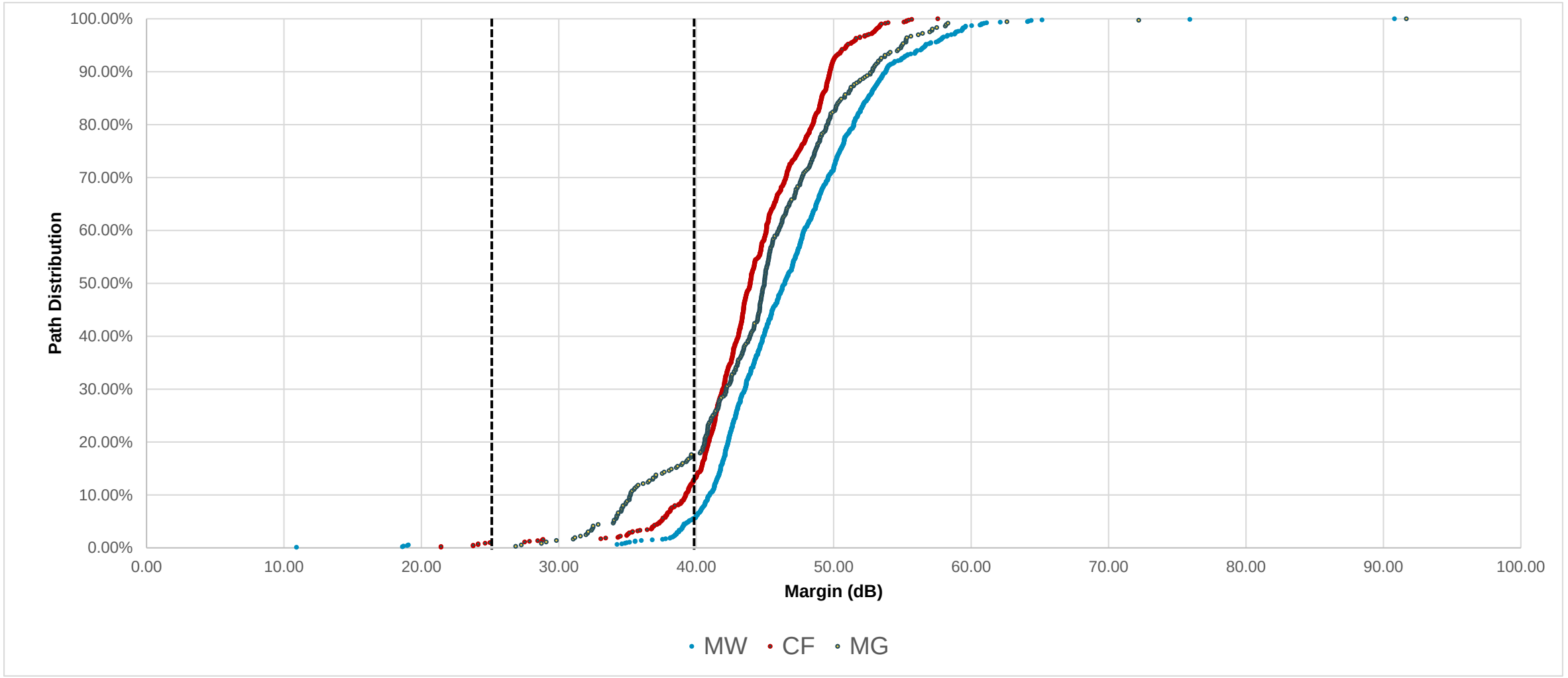
Margin by Radio Service for Paths with Single Modulation Listed in ULS

Critical Public Safety Links typically have even greater margins



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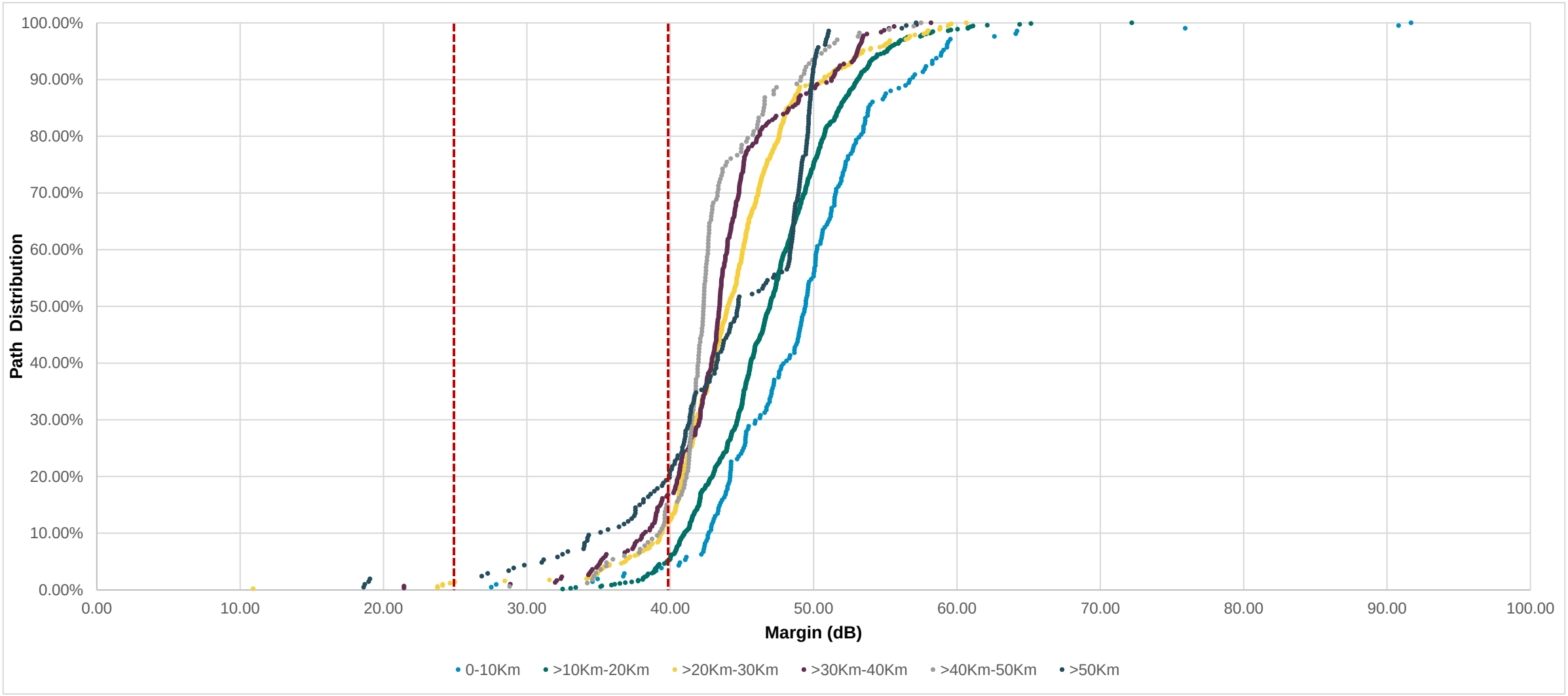
Margin by Path Length for Paths with Single Modulation Listed in ULS

As expected, shorter links have more margin



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Paths terminating near people generally have additional margin

- RKF estimated 2020 population density based on USCB projections to divide the country into urban, suburban, rural and barren areas for each gridded square
  - Approximately 1 square kilometer grid
- Used this grid to categorize FS receivers as being in urban, suburban, rural, and barren areas
- Most frequently cited corner case—high rise in FS beam—likely only applicable in urban and suburban areas
- Urban receivers have 2.39 dB more margin on average than those in barren areas

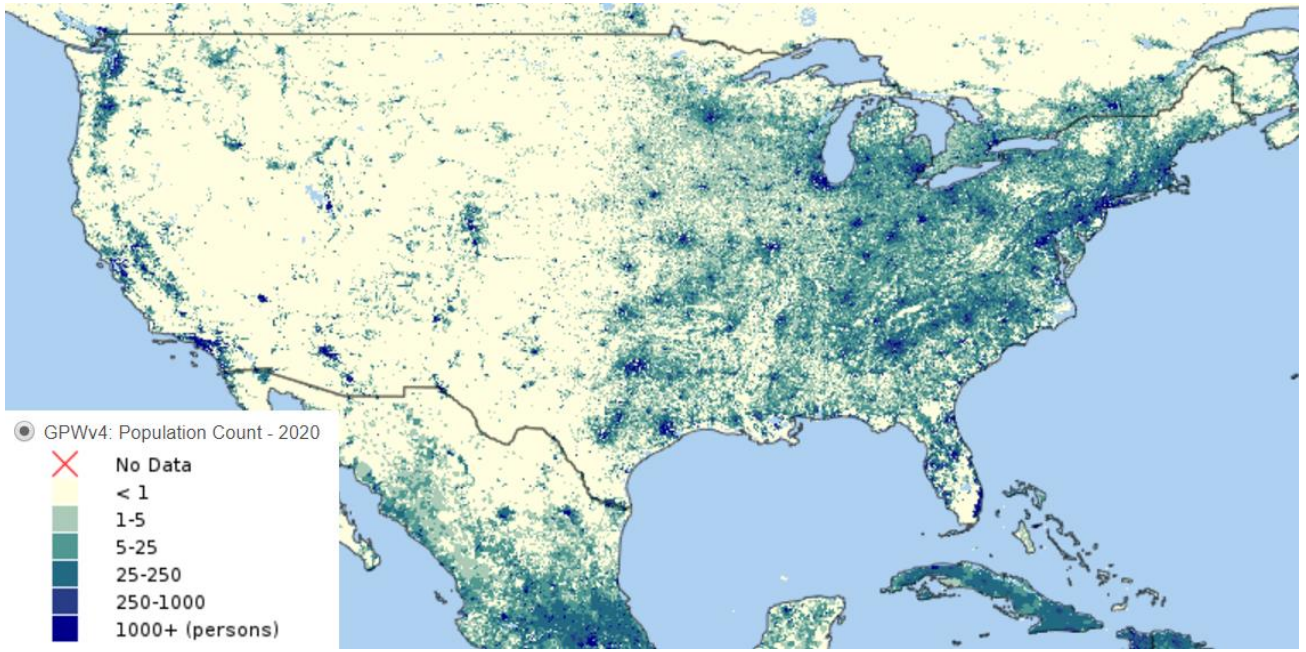

Figure 3-3 - 60 Arcsecond Resolution of Census Bureau Population Count Map

Receiver Prop. Environment	CONUS Population*	Total Links	Avg. Link Length	Avg. Link Margin
Urban	71.2%	261	18.85	47.46 dB
Suburban	9.5%	107	17.85	46.22 dB
Rural	9.3%	215	20.29	45.84 dB
Barren	10%	1527	29.74	45.07 dB
Total	100%	2110	26.83	45.50 dB

Reference: RKF Report, Page 16
*Table 3-3 – Population Distribution

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Conclusion for Paths with Single Modulation Listed in ULS

The Commission can confidently enable low power indoor and very low power portable devices

- Paths with a single modulation on average have over 45 dB in link margin
  - Margin beyond that required to achieve the FS link design target (e.g., 25-40 dB as stated by the FWCC) is by definition excess margin
- 50% of the links registered with a single modulation are 21 km or less
  - Such paths typically have greater margin than longer paths
  - Such paths may also be less susceptible to multipath fading
- FS links terminating in urban and suburban areas are typically shorter than links terminating in rural and barren areas
  - Skyscrapers and other tall buildings are typically located only in urban and suburban areas

ANALYSIS OF LINKS LISTING MULTIPLE MODULATIONS IN ULS

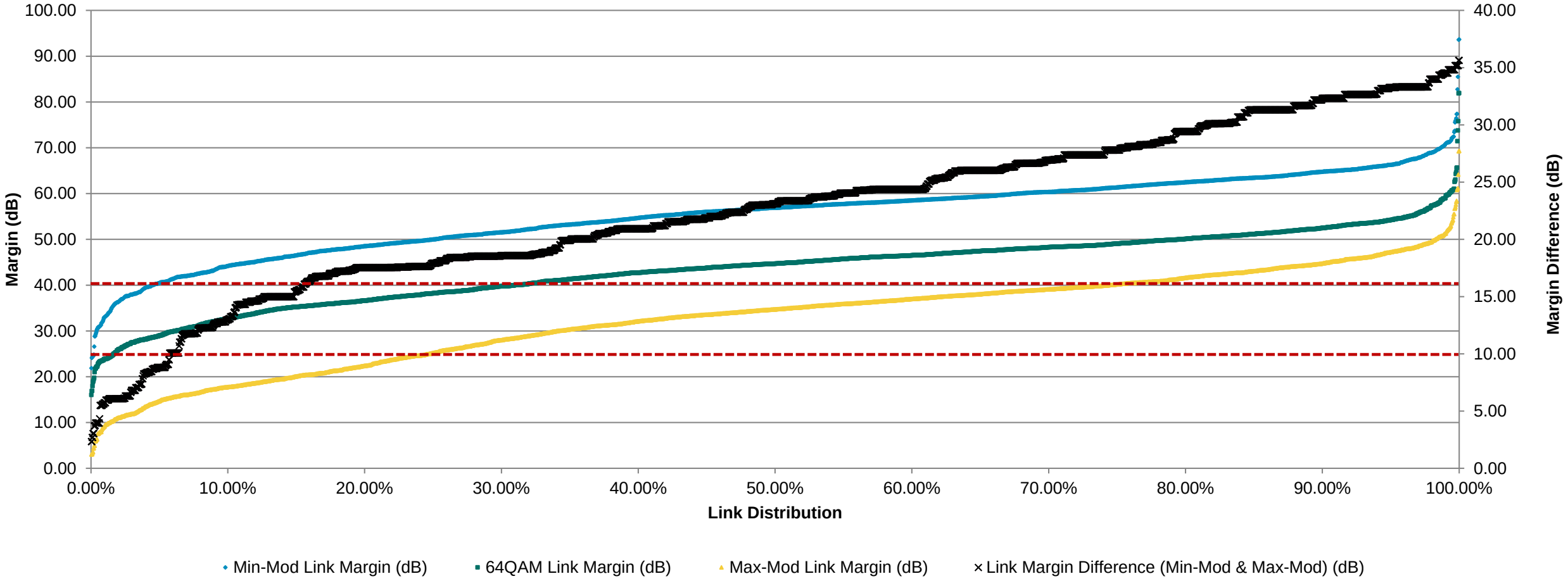
Multiple Modulation Analysis

- There were 3304 new links with multiple modulations listed in ULS
- Modulations ranged from QPSK to 4096 QAM
  - We assume adaptive modulation
- Analyzed the highest modulation listed
  - 64 QAM to 4096 QAM
- Analyzed 64 QAM (or closest listed modulation)*
  - For links listing multiple 64QAMs, we chose the one with the *lowest code rate*
- Analyzed the lowest modulation listed
  - Vast majority were QPSK

*Some links did not have 64 QAM listed. When the closest listed modulation was lower (e.g., 32 QAM), we selected the highest code rate for that modulation. When the closest listed modulation was higher (e.g., 128 QAM), we selected the lowest code rate

Margin Distribution for 3304 Paths Assuming Minimum Modulation, 64 QAM & Maximum Modulation

Accounting for adaptive modulation reveals an average of over 22 dB in additional margin before link reliability is affected



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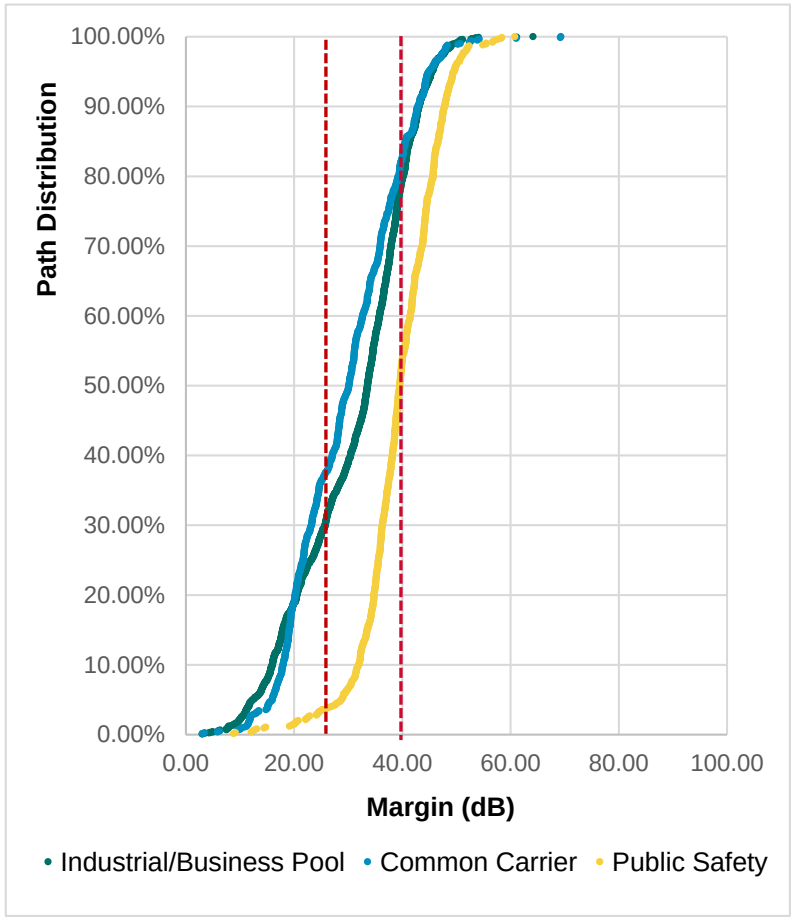
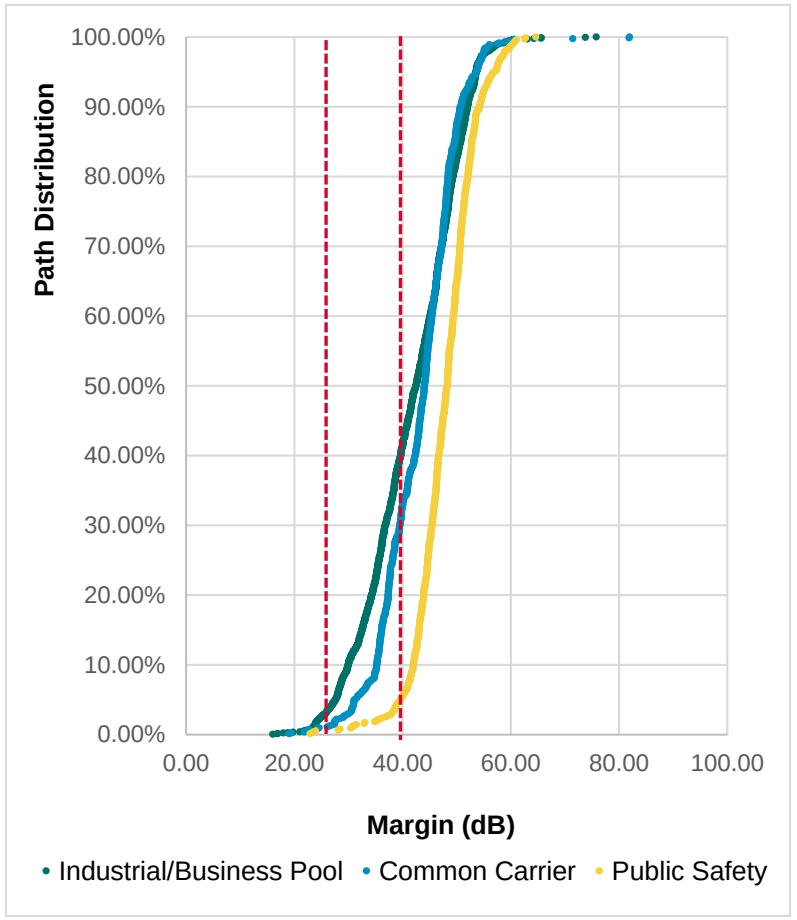
Margin Distribution for 3304 Paths Listing Multiple Modulations (by Radio Service)

Nearly all Common Carrier and Public Safety Links greatly exceed even 40 dB margin at lowest modulation

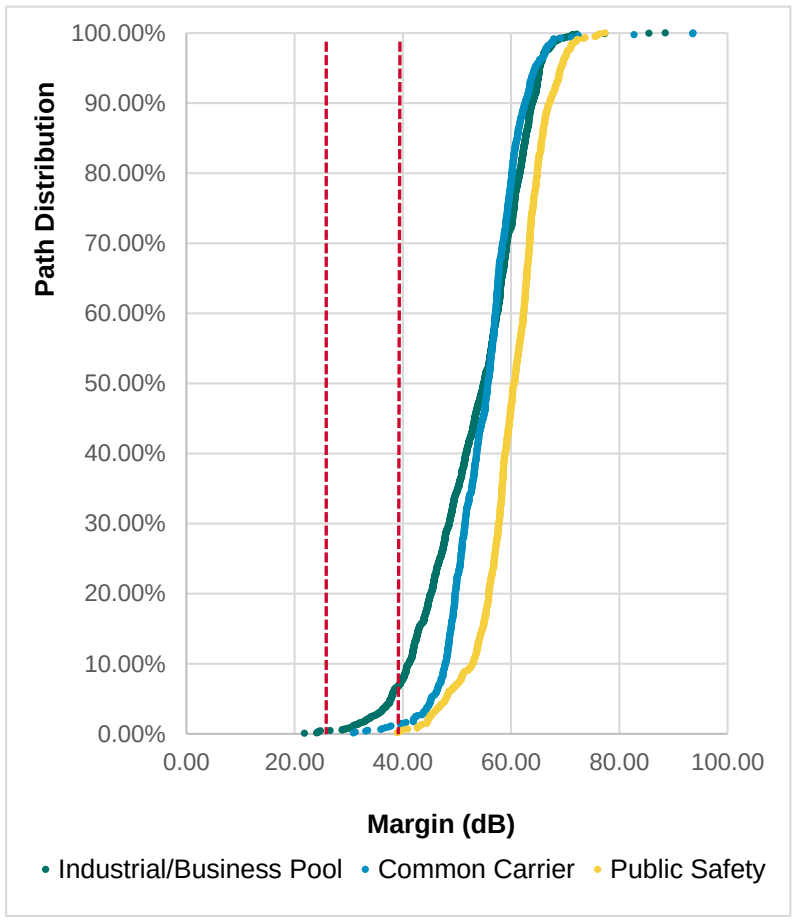
Highest Listed Modulation



64 QAM Modulation



Lowest Listed Modulation



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Conclusion for Paths with Multiple Modulations Listed in ULS

The Commission can confidently enable low power indoor and very low power portable devices

- When adaptive modulation is used, all sources of interference (e.g., multipath fade, other licensed services, unlicensed services) would need to exceed the margin required for highest modulation before throughput drops
- There is an additional 22.62 dB average link margin delta between the lowest modulation and the highest modulation listed
  - This means that corner case RLAN interference would have to exceed all of the margin necessary for the lowest modulation prior to any link outage
  - Anything less than this would lead to a reduction in throughput
- Public safety links have the largest margin of all services

Thank You